San Luis Obispo Botanical Garden Amphitheater Bench Project – Concrete Formwork Construction

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This paper summarizes the efforts towards constructing formwork for 10 concrete benches. The formwork construction is a part of the San Luis Obispo Botanical Garden amphitheater seating senior project. The project included the design, construction, and installation of precast concrete benches to create seating for 40 people. The project was completed by Kyler Cruz, Brandon Keefer, Sydnee Greer, Makenna Gitchell, Devin Barthmaier, and Anthony Masarweh. The concrete formwork consisted of plywood, 2x4 lumber for bracing, rebar cages, and foam inserts. The key considerations for this scope of work included: reinforcing rebar, the number of forms built, formwork failure, and the overall weight of the benches. The initial estimate for formwork bracing material was too conservative which resulted in construction taking longer than initially planned, as well as increased spending on materials. The team also struggled to secure the rebar and foam core inside the formwork which created more work during the concrete pour. Despite the challenges that occurred, the formwork was completed in eight days and in time for the scheduled concrete pour. The formwork did not fail during or after the concrete pour and all 10 benches were poured successfully.

Key Words: Precast Concrete, Benches, Formwork, Bracing, Rebar

Introduction

This project based senior project is located in the San Luis Obispo Botanical Garden (SLO Botanical Garden). The SLO Botanical Garden is home to 150 acres of garden space and currently, 3 main garden displays. Because of the amount of land they have to maintain, the nonprofit organization is consistently looking for volunteer work and community service projects to help keep their gardens in working condition. One area in particular, the amphitheater, was in need of bench style seating. This became the project Kyler Cruz, Brandon Keefer, Sydnee Greer, Makenna Gitchell, Devin Barthmaier and Anthony Masarweh took on as a senior project. The Client, SLO Botanical Gardens, wanted bench seating for 40 people in hopes of renting out the space for weddings and other events. This meant the seating had to be designed to fit the space, be comfortable to sit on, and require minimal maintenance. Because of the scale of the project and the short duration of 10 weeks, the project team members were assigned roles. Devin Barthmaier and Sydnee Greer were in charge of modeling and design, Anthony Masarweh acted as the owner's representative, and Brandon Keefer, Makenna

Gitchell, and Kyler Cruz were in charge of construction and logistics. After meetings with the client, Devin Barthmaier and Sydnee Greer began working on bench designs and site layout drawings. The approved final design was 10, 8-foot-long precast concrete benches with a depression on the top of the bench for composite decking, see figure A. Upon owner approval, the team reached out for funding and started planning the construction activities. Funding was generously provided by the Construction Management Advisory Council (CMAC) and the SLO Botanical Gardens. We were also able to secure materials through Hayward Lumber, Air-Vol Block, Inc., and CalPortland. Once materials were ordered, the construction team began constructing the forms in preparation for concrete. This report will cover the construction of the formwork and lessons learned from this scope of work.

Formwork Construction

Formwork is one of the first steps of any concrete project and it must be constructed and reinforced properly. The final approved design of the concrete benches was a solid box with a depressed side on the top for composite lumber to sit. This made the formwork design relatively simple. The shape of the formwork would be a box with a strip of plywood on the top to help form the depression on the top of the bench, see figure B. Despite the simple formwork shape, there were several key factors to address when constructing the formwork. These factors were: reinforcing rebar, choosing how many forms to build, bowing or formwork failure, and the overall weight of the benches.

Rebar

The rebar design for the benches was a simple cage design. The cages had rebar running the length of the bench on the top and bottom connected with rebar hoops. Because the cages had no complex bends or ties, choosing to construct the rebar cages on-site helped reduce cost and decrease transportation logistics. #3 rebar cut in 8-foot sections and pre-bend hoops were ordered from Air-Vol Block. This allowed the construction team to pick up the rebar from Air-Vol Block and transport it back to the Simson Strong Tie Materials Demonstration Laboratory, located on Cal Polys' campus. Had the team made the decision to order prefabricated rebar cages, they would have not fit in a regular pickup truck and special transportation would have had to been arranged. This would have increased the rebar on the project. Once the rebar was on-site, the team had to cut the 8-foot rebar sticks down so that the rebar would be fully encased in concrete. Then the team was ready to construct the cages.

The construction of the cages took 4 hours with 4 team members thanks to an efficient system to tie the cages. The team used a scrap 2x4 board and suspended it at waist height. This allowed for the rebar hoops to hang off the 2x4 board at the correct spacing. Then the team of 4 could hold the horizontal rebar stick and tie it to the hoops at waist height, reducing the fatigue caused by working on the ground and sore backs the next day. The tie wire held the rebar together using a cross tie method and tightened with rebar pliers. Once all the cages were constructed, Dobie blocks were tied to the bottom of the cages so the cage could be raised off the ground when installed in the formwork, see figure C.

Number of Forms

With a total of 10 benches to construct, the decision to pour five benches and reuse formwork, or to pour them all at once was important. There were positives and negatives to both methods, but the team decided to build 10 bench forms and pour them all at once. There were a number of reasons why building 10 forms was the decision. Since the amount of funding we had received was enough to

cover the additional lumber costs; we would only have to set up and clean up one concrete pour. In addition, construction of the formwork was efficient enough that building 10 forms would not take much longer than it would have to just build five. The decision to build 10 forms at once meant that the team spent two full days cutting the material from a cut sheet that was developed. We used a circular saw and a guide to cut the ¾" Pro-Form, plywood designed to be used for concrete forms, and a chop saw to cut the 2x4 lumber bracing. After we cut all the material, we were able to construct the Pro-Form and the majority of the bracing in 1 day using 2" and 3" construction screws.

Formwork Bracing

As with any concrete formwork, you want to ensure that it has enough strength to resist deformation or failure. The bench design called for around .8 yards of concrete in each bench and, because of their length, formwork bending was a major concern. To brace the Pro-Form boxes we used 2x4 lumber both vertically and horizontally around the box. As seen in figure B, vertical 2x4 lumber ribs were attached on all four sides perpendicular to the length of the bench. The side members were cut taller than the finished surface of the bench to allow room for finishing the concrete. The ribbed bracing helped keep the box from blowing out in the middle where the force imposed by concrete was going to be strongest while also keeping the width of the bench consistent. Another added benefit of the ribs was that the 2x4 lumber underneath the box brought the benches off the ground and proved a space for forklift forks to slide underearth the bench for transporting. Once that formwork bracing was attached to the Pro-Form with 2" construction screws, bracing was added to resist the bending of the 1.5' high sides of the bench. Even though we had the 2x4 lumber ribs, they were installed flat against the formwork as seen in figure E. When 2x4 lumber is placed flat against the surface it does not resist bending as well as when the lumber is placed on edge. This meant the weight of the concrete could have caused the 2x4 lumber to bend outward and create a balloon effect on our formwork sides. To solve this issue, we installed a ring of 2x4 lumber that went all the way around the box horizontally. We screwed it in from the inside of the formwork through the ribbed bracing using 3" construction screws. This 2x4 lumber bracing was placed on edge, the longer side was perpendicular to the bench side as seen in figure F, which results in more resistance to bending forces. While we ended up buying more lumber than we initially estimated, it was important that this formwork could resist the weight of the concrete as well as the weight of people walking over it during the concrete pour.

Weight of Benches

Weight was something that had to be accounted for in every step of this project. We were not able to pour the benches on-site, so we had to build the formwork and pour the benches off site and then transport them. The biggest hurdle with moving these benches was their total weight. One bench is 24 cubic feet and with the average weight of concrete around 150 pounds/cubic feet, one bench would around 3,600 pounds. This would require equipment that the team did not have access to. To combat the weight problem the team implemented two solutions to lower the weight.

To reduce the weight of each bench, lightweight concrete was used instead, as well as adding a foam core within the rebar cage. To install the foam core, 1.5" thick foam was purchase and cut into 1' wide strips. Four strips were tied together to create a 6" tall by 1' wide foam core that was tied in the middle of the rebar cage of each bench. This would reduce the concrete volume in each bench by 3.5 cubic feet, bringing the concrete volume down to 20.5 cubic feet. However, the forklift in the Simson Strong Tie Materials Demonstration Laboratory had a max capacity of 3000 pounds. so lightweight concrete had to be used as well. The lightweight concrete ordered from Cal Portland had a weight of

115 pounds/cubic foot. This reduced the weight of concrete down to around 2,360 pounds, a manageable weight to move with forklifts and a trailer.

Lessons Learned

With a large scope of work and a tight deadline, the team learned a lot about everything from permits to finishing concrete. In regard to the formwork scope of this project, there are a couple of things that would be done differently if we were to do this project again. The two biggest lessons learned in formwork scope were designing formwork bracing prior to material estimating and securing everything before the concrete arrives.

During the estimating scope, we did not account for the amount of 2x4 lumber bracing that ended up being used to brace the forms. When estimating for the 2x4 lumber we discussed minimal bracing. We did not take into account the length of the forms and the resulting pressure the forms would be feeling when filled with concrete. This resulted in our initial lumber order only including enough material to brace 3 out of the 10 benches. Because of this underestimate in our first material order, we had to pick up the extra 2x4 lumber ourselves as we could not afford the time delay or cost of having it delivered. This also added extra construction time into the build schedule which we did not account for. When constructing the bracing, we did not think about the different ways to attach the 2x4 lumber and how that would have an effect on the materials strength. Next time, more planning and consulting should happen before we estimate the lumber needed. This would help keep material costs from increasing and keep us on schedule, minimizing additional construction that was not planned for.

Despite our efforts to construct the rebar cages with the foam core inside, we failed to secure the rebar and the foam to the formwork. We discussed the situation of the rebar cage moving during the concrete pour and the foam core moving around inside the rebar cage, but we didn't believe it would affect our production on the pour day. However, the rebar cage and foam floated to the top of each bench. We solved the issue by pouring half the bench, vibrating and re-centering the rebar, and foam and then coming back a couple of minutes later to pour the rest of the bench. Had we spent more time securing the foam in the middle of the rebar and securing the rebar to the bottom of the formwork we could have made our pour more efficient and eliminated a problem that occurred during the pour.

Conclusion

In conclusion, the construction of these benches was successful. The construction took a total of eight days, meeting the deadline for the concrete pour. The formwork did not fail or bow during the concrete pour. From designing, estimating, and constructing formwork to pouring concrete in them, we were able to learn from the successes and failures of this project and truly embody the learn-by-doing motto here at Cal Poly. This experience has and will benefit everyone on the team in both future projects and in our professor careers in the construction industry.

Photos

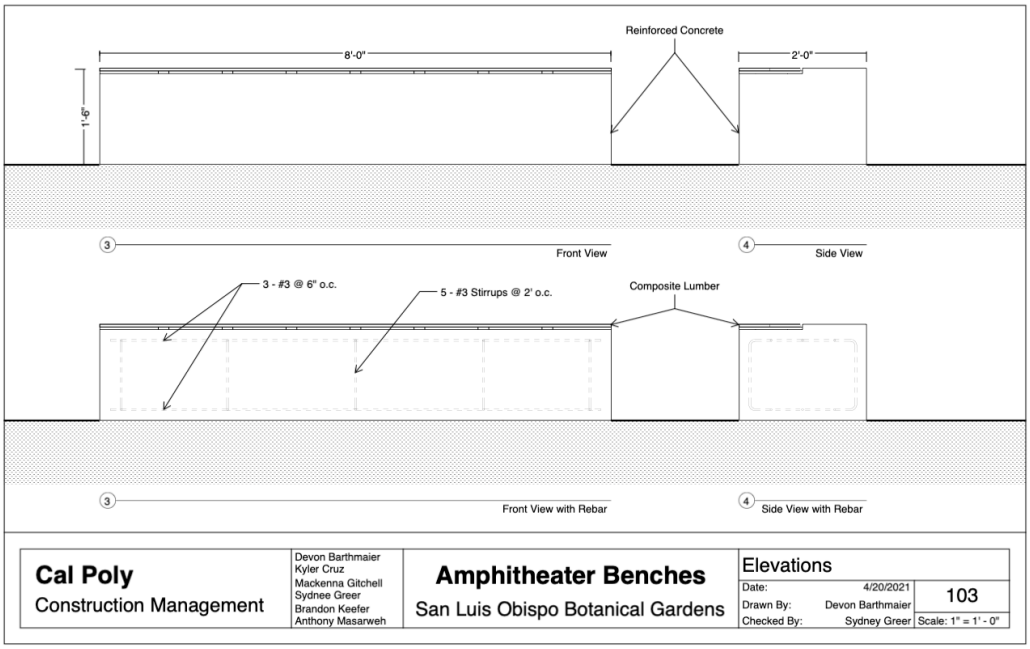

Figure A –Design

Figure B – Completed Formwork

Figure C – Completed Rebar Cage with Foam Not Tied In

Figure D – Constructing Pro-Form Box

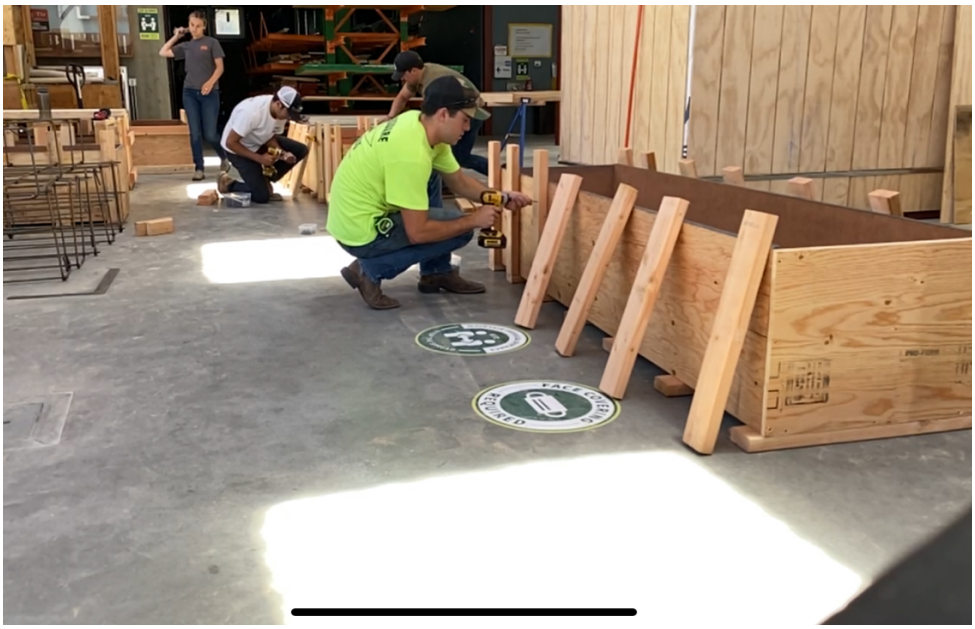

Figure E – 2x4 Lumber Bracing being installed flat against the Pro-Form

Figure F - 2x4 Lumber Bracing on Edge Perpendicular to Bracing Ribs